



Responding to Extreme Weather and Climate Events

Adaptation Strategies and Information Needs

In recent years, communities have faced a variety of extreme weather and climate events, which have become more severe, more frequent, and more costly. From drought to storms to tidal surges, these events have devastating impacts on our nation's critical infrastructure, including our drinking water and wastewater systems. Because the single biggest threat to human health and economic livelihood is lack of access to clean and safe water, water service providers must be prepared to deal with changing weather conditions.

With rising public concern about extreme weather events, a forum of drinking water, stormwater, and wastewater utility practitioners called on national organizations to help advance and share knowledge on preparing for, and responding to, such events. This workshop series is intended to contribute to the national dialogue.

The following case study series is based on workshops in six communities that have experienced extreme events, including floods, storms and derechos, sea level rise and storm surge, drought, and unseasonable frost.

These Case Study Highlight:

- **For Utility Managers:** Lessons learned on building resilience, including useful tools and data sources
- **For Policy Makers and the Research Community:** Information on how water utilities plan, including information needs
- **For Communities:** Opportunities for dialogue

A final report will be available late 2013.

Extreme Weather Event Workshop Locations



A Collaborative Approach to Managing Extreme Weather and Climate Events

As extreme weather events appear to be more commonplace and have the potential to disrupt all types of water services, a forum of drinking water, stormwater, and wastewater utility practitioners called for a collaborative approach to advancing industry knowledge. Through a series of regional workshops, WERF and WaterRF, along with collaborating partners NOAA, U.S. EPA, Concurrent Technologies Corporation, and Noblis, have begun documenting experiences and lessons learned and synthesizing collective information on weather-related data needs. Key outcomes and findings from these workshops are highlighted below.

Lessons Learned

Cascading Nature of Extreme Events:

Instead of one dominant event, localities are dealing with multiple types and occurrences of extreme events, many of which have become more severe and more frequent in recent decades.

Water Services as Critical Infrastructure:

Water services are critical, and water infrastructure must be prioritized.

Risk Management:

The community must understand their risk and define their risk tolerance.

Emergency Response and Long-Term Planning:

To build resilience, water utilities and communities must embrace both emergency response and long-term preparedness.

Community Decision-Making within a Watershed:

The complex array of decisions needed to support resilience within a watershed requires coordination across water service areas and jurisdictional boundaries.



Water utilities can face devastating infrastructure and cost impacts from extreme weather events.

Leadership and Innovation:

Communities need leadership to help navigate the path to resilience.

Active Engagement in Acquiring Information and Tools:

There is no 'silver-bullet' decision support tool.

Multi-Disciplinary Collaboration:

Multi-disciplinary collaboration and communication increases access to actionable information for science-based decision making.

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Case Study California: Russian River Watershed



Water Resource Strategies and Information Needs in Response to Extreme Weather/Climate Events

Russian River Basin



Water Trends

The 110-mile long Russian River runs from Mendocino County to the Pacific Ocean in Sonoma County. This region typically has warm, dry summers and cool, wet winters, in which highly variable precipitation results in rapid, brief, and dramatic runoff. More than 93% of rainfall occurs in winter, so maximizing storage for yearlong water supply is a priority.

In the past 60 years, 34 of 39 floods were related to a meteorological phenomena termed “atmospheric rivers.” These narrow bands, a few hundred kilometers wide and two thousand kilometers or more long, transport water vapor from the tropics toward the poles. Projected increases in rainfall frequency and intensity associated with atmospheric rivers increases flood risk.

In recent decades, this region has had more widespread drought because of precipitation deficits and higher temperatures. This is accompanied by reduced snow cover, earlier snow-melt run-off, reduced streamflow and reservoir levels, and drier soils. Periods of surface water decline often result in higher groundwater use, stressing both systems. Because of the number of extreme dry years, the National Integrated Drought Information System (NIDIS) has included this area as a pilot study for a drought early warning system for better-informed and well-timed decisions to reduce impacts and costs.

Governing Structures

SCWA provides naturally filtered drinking water to 600,000 people, as well as flood protection and wastewater services. The US ACE and SCWA operate Coyote Valley and Warm Springs Dams in the Russian River Watershed where US ACE is responsible for flood control operations, while SCWA is responsible for water supply operations. Local communities such as the City of Santa Rosa manage their own stormwater and wastewater systems.

The Story in Brief

California's Russian River watershed has a history of variable weather, but recent events reveal an emerging pattern that is more erratic and unpredictable. The 2006 New Year's Day flood, the 2007-2009 drought, and an unusually intense period of frosts in spring 2008 are examples of this pattern. Such cascading weather-driven events require management of both flood risk and water supply in balance with environmental needs, and they illuminate the interdependent challenges water resource managers face.

2006 New Year's Day Flood

Impacts

Exceptionally heavy rains hit northern California from December 26, 2005, to January 3, 2006. The Russian River rose above flood stage at all Sonoma County gauge stations. At Guerneville, the hardest-hit town, the river crested more than ten feet above its 32-foot flood stage. The city of Santa Rosa saw near-record rainfall totaling 17.6 inches.

The Federal Emergency Management Agency (FEMA) declared a major disaster. More than 100 roadways were blocked because of flooding and landslides. Some 2,100 business and residential properties were inundated and 50,000 residents were without power. Sonoma County business and residential damages were estimated at \$104 million.

In the Laguna de Santa Rosa wetlands, designed to protect Santa Rosa and surrounding areas, record-peak flows resulted in severe flooding, overbanking, erosion, and sedimentation. Local stormwater systems were overwhelmed, flooding streets and buildings.

Meanwhile, the Laguna Wastewater Treatment Plant and its storage ponds that hold recycled water flooded, causing release of partially treated wastewater. Structural damage to roadways limited access for plant personnel during recovery operations.

Utility and Community Response

The US Army Corps of Engineers (US ACE) and the Sonoma County Water Agency (SCWA) cooperate in managing Warm Springs Dam on Lake Sonoma and Coyote Valley Dam on Lake Mendocino. Their combined efforts, in concert with information provided by NOAA's California/Nevada River Forecast Center (CN RFC), controlled releases to avoid worse flooding. US ACE and SCWA had to weigh reserving “freeboard” capacity to contain potentially more rain against using that capacity to maintain storage for adequate supply during periods of low rainfall. Flood management decisions are time-sensitive, and improved information for forecasting and modeling is needed to aid multiple types of decision making, including emergency operations. Recent work by NOAA on forecasting atmospheric rivers holds promise for local decision makers.

At the Laguna plant, operated by the City of Santa Rosa, managers installed a system to monitor water flow during future wet-weather events, and installed a combined heat and power system to provide emergency power as well as 30% of the plant's regular energy needs. SCWA instituted a stream maintenance program that tries to balance the competing goals of reduced flood risk with enhanced riparian and instream habitats.

Drought and Frost of 2007-2009

Impacts

A three-year drought hit on the heels of the 2006 flood, affecting Sonoma County's water environment, economy, and water supply. Surface water and groundwater recharge significantly declined. Lake Mendocino, a major water reservoir, was dangerously close to drying up. To preserve water supplies, the State Water Resources Control Board (SWRCB) allowed reduced releases from the lake below minimum in-stream flow requirements. Local water rationing of up to 50% also was imposed.

“We use the [Russian River] as a natural conveyance system and natural filtration system of sands and gravels for water withdrawal. We are very much reliant on the natural environmental system. This has a lot of consequences [related to] managing that system for extreme events.”

Jay Jasperse, Chief Engineer
Sonoma County Water Agency (SCWA)

A series of workshops focusing on extreme events and water resources, co-sponsored by the National Oceanic and Atmospheric Administration (NOAA), US Environmental Protection Agency (US EPA), Water Environment Research Foundation (WERF), Water Research Foundation (WaterRF), Concurrent Technologies Corporation (CTC), and NOBLIS.

NOAA EPA WERF WaterRF CTC Noblis

In spring 2008, unusually intense frosts occurred during the drought. The region's world-renowned vineyards and wine-making industry dominate the local economy. While wine grapes are generally a low water-use crop, during freezes, one way to protect new spring growth from frost and potential crop loss is by spraying water on the vines, coating them with an ice shield. The combination of drought and repeated frosts created high immediate water demands.

River flows, typically 500 - 1000 cfs or more, were already extremely low due to dry conditions. When grape growers sprayed vineyards to prevent damage, flow dropped to 168 cfs. NOAA's National Marine Fisheries Service (NMFS) discovered dead juvenile coho and steelhead trout in the Russian River and one of its tributaries.

The SWRCB, already encouraging water conservation efforts, responded with regulations to restrict and govern water use for frost protection. Salmon fishermen endured canceled and shortened seasons between 2008 and 2010. Tensions between conservationists and the grape industry flared and the agricultural community challenged the legality of these regulations. (In September 2012, the court found in favor of the grape growers and set aside the frost regulations.)

Utility and Community Response

SCWA, the NMFS, and others examined frost protection practices and found that limited prediction capabilities and lack of coordination between grape growers and the reservoir releases were factors in the extreme drawdown. As a result, NOAA began working with SCWA to improve frost event forecasting, supporting SCWA's efforts to coordinate with grape growers. SCWA also worked with the USGS to increase the number of stream gauges on the Russian River to improve the monitoring network to support reservoir operations. In Mendocino County, the Russian River Flood Control and Water Conservation Improvement District led efforts with its grape growers to significantly reduce water diversion from the river during frosts by constructing storage ponds for frost protection.

These ongoing efforts have improved the use of forecasting tools, coordination procedures, and water management projects so that impacts from frosts are much less than in the past. In addition, NOAA forecasting tools are expected to improve summer heatwave predictions, thus helping growers coordinate irrigation schedules up to 72 hours in advance. Meanwhile, recognizing that

"you can't do it alone," SCWA engaged in a variety of partnerships including the Sonoma-Marín Saving Water Partnership. Ten utilities have committed to provide a sustained level of funding to implement best management practices to conserve water while focusing on programs that benefit the region.

Managing for multiple objectives lies at the heart of integrated water resource management and guides SCWA's innovative approaches for supply management. Groundwater banking and aquifer storage systems during times of high precipitation are being explored to control flooding. Supply is being extended further by reusing treated wastewater for agriculture and urban landscaping, stemming freshwater withdrawals.

Wastewater treatment plants achieve multiple objectives by discharging in a way that supplements water supply, protects water quality, and generates energy. The Laguna Wastewater Treatment Plant conveys about two-thirds of its treated wastewater to the Geyser Project, where it is used to recharge the geyser steam-field to generate 100 MW of thermal energy daily.

Partners, such as the non-profit Pepperwood Preserve, are exploring science-based conservation to protect biodiversity and link functioning ecological landscapes using conservation easements and protected watershed areas. Scientific collaboratives are participating in a regional integrated monitoring strategy to advance understanding of the impacts of climate change on terrestrial and aquatic ecosystems. In early 2012, SCWA's Board of Directors established the Independent Science Review Panel to promote science-based management and policies. SCWA also is leading collaborative stakeholder-driven groundwater management programs in two basins.

Looking Forward

Communities in the Russian River Watershed have historically nurtured a collaborative approach for solving complex problems. Their increasingly sophisticated understanding enables an integrated resource management approach. Water and natural resource managers, scientists, and elected officials are overcoming uncertainty in climate projections by investing in the monitoring, research, tools, and dialogue needed to build resilient responses to the impacts of a changing climate.

To learn more about how the water sector is responding to extremes, visit:

<http://www.cpo.noaa.gov/ClimatePrograms/ClimateSocietalInteractionsCSI/SARPPProgram/ExtremeEventsCaseStudies.aspx>

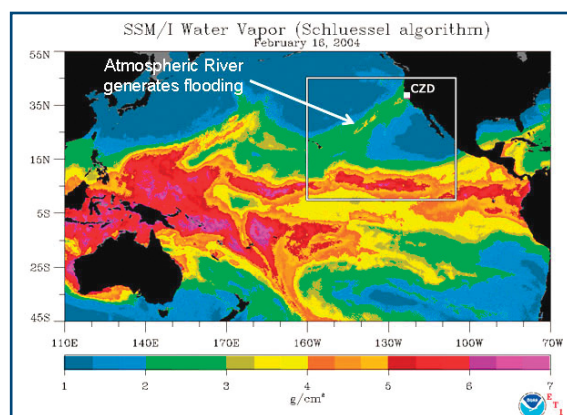
Lessons Learned

- Develop implications of scenarios, including low-probability events.
- Identify opportunities to address multiple challenges through integrated programs and diverse strategies that contribute to sustainability.
- Look at the entire watershed to identify the greatest benefits for the lowest cost.
- Develop partnerships to help leverage resources, coordinate activities, and incorporate innovative approaches that result in faster progress and collective learning.
- Form partnerships with other stakeholders, including regulatory

agencies: work on problems ahead of regulation instead of waiting for a one-size-fits-all route.



(Top/Middle) Frosts in the middle of severe drought in 2008 undermined local water management efforts when grape growers used large quantities of water to coat grapes with protective ice. (Bottom) Atmospheric rivers are narrow bands transporting columns of water vapor that result in extreme rainfall.



Useful Tools and Resources

- NOAA NWS California/Nevada River Forecast Center (<http://www.cnrfc.noaa.gov/>) – hydrologic and meteorological data
- USGS GSFLOW (<http://water.usgs.gov/nrp/gwsoftware/gsflow/gsflow.html>) – coupled groundwater and surface-water flow simulation
- CocoRaHS (<http://www.cocorahs.org/>) – precipitation mapping
- SCWA and USGS integrated flood control/groundwater recharge studies (<http://www.scwa.ca.gov/srgw-studies/>)
- NOAA Hydrometeorological Testbeds (hmt.noaa.gov/) – information and prototype solutions
- Golden Gate Bridge long-term, sea-level rise data (<http://tidesonline.nos.noaa.gov/geographic.html>)

Information Needs

- Better regional weather forecasting and decision support tools to support operational and emergency planning decisions
- Additional flow monitoring data and use of new technologies; e.g., light detection and ranging (LIDAR), radar, collaborative monitoring

Case Study

Georgia: Upper Apalachicola-Chattahoochee-Flint River Basin



Water Resource Strategies and Information Needs in Response to Extreme Weather/Climate Events

ACF Basin



Water Trends

The Chattahoochee River, its tributaries, and Lake Lanier provide water to most of the Atlanta and Columbus metro populations. The river is the most heavily used water resource in Georgia. The northernmost reservoir in the ACF Basin, Lake Lanier supports hydropower, flood management, navigation, fish and wildlife, recreation, water supplies, and water quality. Operated by the Army Corps of Engineers, it stores 65% of the basin's water, fed by the Chattahoochee River.

In the last 50 years (1960-2009), all major Georgia river basins, including the ACF, experienced intensified droughts: average rainfall declined between 9% and 16%, soil moisture between 3% and 6%, and watershed runoff between 16% and 27%; evapotranspiration increased between 1% and 3%. This trend is expected to continue. (Georgia Water Resources Institute, 2011). Projections of reduced rainfall and population growth, indicate that the ACF basin is likely to be vulnerable to water deficits by 2060.

In addition, the region experienced two 500-year floods between 2007 and 2012 as a result of record rainfall, demonstrating the potential for more frequent and extreme rainfall events in an increasingly urbanized setting.

Governing Structures

Protective legislation includes the federal Clean Water Act and state plans, such as the Water Stewardship Act of 2012, the State Drought Management Plan, the Flint River Drought Protection Act, and the 2004 Comprehensive State-Wide Water Management Planning Act. The latter calls for the state to prepare a comprehensive water plan. There are 11 regional water-planning councils. For the most part, water and wastewater utilities are under the jurisdiction of cities and counties.

The Story in Brief

Communities in the Apalachicola-Chattahoochee-Flint River Basin (ACF) in Georgia, including Gwinnett County and the city of Atlanta, faced four consecutive extreme weather events: drought of 2007-08, floods of September and winter 2009, and drought of 2011-12. These events cost taxpayers millions of dollars in damaged infrastructure, homes, and businesses and threatened water supply for ecological, agricultural, energy, and urban water users. Water utilities were faced with ensuring reliable service during and after these events.

Drought of 2007-2008 and 2012

Impacts

Northern Georgia saw record-low precipitation in 2007. By late spring 2008, Lake Lanier, the state's major water supply, was at 50% of its storage capacity. The drought, combined with record-high temperatures, caused an estimated \$1.3 billion in economic losses and threatened local water utilities' ability to meet demand for four million people. Similar drought conditions unfolded in 2011-2012, during which numerous Georgia counties were declared disaster zones.

Reduced rain affected recharge of the surface-water-dependent reservoir. It reduced flows, dried tributaries, and caused ecological damage in a landscape already affected by urbanization, impervious cover, and reduced natural flows. Downstream, agricultural production was harmed, exacerbating tension over perceived levels of urban water use. Landscapers and nurseries, among major suburban economic sectors, were hurt by the outdoor water ban imposed by local governments. Simultaneously, hydropower energy production, which is dependent on Buford Dam releases, conflicted with the need to preserve water storage for municipal supplies. In short, decisions by independent sectors had cascading effects.

Water utilities in Gwinnett, Cobb, and DeKalb counties were faced with two sets of challenges: Ensuring adequate supply to customers and complying with environmental regulations. Unlike with flood events, infrastructure damage was not a primary concern. Rather, utilities had revenue loss associated with their response actions. For example, utility revenues dropped when water restrictions were imposed, resulting in hiring freezes and cut contracts. Meanwhile, drinking water treatment costs rose due to increased turbidity (i.e., suspended solids when there is too little fresh inflow) from water sources.

To complicate matters, the Army Corps of Engineers granted the Georgia Environmental Protection Department (EPD) request to reduce water releases from Buford Dam to 650 cubic feet per second for three months to preserve water supply for the coming summer, below Atlanta's 750 cfs discharge permit standard. Environmental groups expressed alarm that this would harm downstream and Gulf ecosystems.

Utility and Community Response

Gwinnett County adopted a tiered billing structure in which water prices rose with use, reducing consumption by 20%. Priority responses focused on leak detection and repair. To deal with reduced revenue, the county renegotiated electrical rates, insured capital project management, and closed older facilities. Neighboring Cobb County took the initiative to impose an outdoor water ban (an action the state later also implemented).

Recognizing the need to improve natural recharge of local streams, utilities promoted green infrastructure and conservation; metro Atlanta used 14% less water in 2011 than a decade earlier. Local environmental groups lobbied for increased water quality monitoring in the river; a second monitoring station was installed.

Several partnerships formed to address critical water resource issues. A notable example is ACF Stakeholders, formed in response to the drought in 2008 and composed of 70 members from Georgia, Alabama, and Florida, including agricultural users, community members, environmental groups, utilities, and several government agencies. In 2011 it approved a five-year plan aimed at reaching consensus on protecting the ecology and businesses that rely on the basin.

"There is nothing simple, nothing one sub-basin can do to solve the problem. The more we talk, the more we study, the more we find out how interrelated and complicated everything is."

Charles Stripling, Chair, ACF Stakeholders

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Floods of September 2009 and Winter 2009-2010

Impacts

In September 2009, intense and prolonged precipitation in north Georgia caused flooding over several days. Disaster areas were declared in 69 of the 159 counties, with the worst flooding in the Atlanta suburbs. Meanwhile, the Chattahoochee River reached the 500-year flood level. Lake Lanier rose by more than 18 feet, coming close to overtopping at Buford Dam upstream of Gwinnett County. Weather stayed wet through the winter of 2009-2010, with heavy rain causing more flooding from over-saturation, requiring carefully controlled dam releases.

In Gwinnett, 11 inches of rain fell in 18 hours, 28 storm culverts under roads collapsed, two wastewater pumping stations were shut down, water and wastewater treatment plants were flooded, and sewers and floodways were inundated. The costs just for stormwater infrastructure evaluation and repairs were \$7.5 million.

Neighboring Cobb County lost tertiary treatment at its R.L. Sutton wastewater treatment plant, had excessive damage to lift stations and underground infrastructure, and faced collapsed structures and fallen trees.

In Atlanta, the R.M. Clayton Water Reclamation Center had severe flooding and damage to primary clarifiers, biological nutrient removal basins, electrical gear, and the blower building. Power outages disrupted treatment processes. Despite extensive recovery efforts, damage remained as of mid-2012. Total wastewater treatment response costs totaled \$55 million.

Utility and Community Response

Flooding presents sudden and urgent challenges, as well as long-term recovery efforts that impose large capital costs from damaged infrastructure. Utility managers must immediately restore critical potable water operations and wastewater treatment services to protect public health. Unreliable electric power, damage to roads and bridges, and lack of landfill capacity to take debris impeded utility efforts to recover and, in the long term, to remediate damage.

Gwinnett County officials report they were better prepared for flooding as a result of three major initiatives that began in the 1990s: the FEMA Floodplain Map Modernization Program, the USDA Natural Resources Conservation Services Watershed Dam Rehabilitation Program, and a new stormwater utility started in 2006 to provide funding for county stormwater operations and capital improvements. When the 2009 flood came, updated maps helped identify at-risk bridges and culverts and confirmed 10 of 14 dams were in compliance with standards due to a stepped-rate structure, which provided funding for infrastructure upgrades.

In Atlanta, the wastewater utility was prepared with a robust and tested emergency response plan. Priority areas were defined so operations could be conducted manually and alternative processes could be used. New emergency purchase authorizations were triggered to provide services for portable pumps and generators, equipment and building cleaning and drying, debris removal, chemical delivery, and full-site restoration. New worst-case scenario planning is helping plan for future “perfect storm” events.

Looking Forward

A broad array of concerned citizens, stakeholders, and government officials are coming to understand that managing water resources for multiple objectives in a context of changing climate requires foresight, communication, understanding, collaboration, and flexibility. Actions underway to build support and inform decisions include monthly conference calls with NOAA to help regional planners understand unfolding events and use of USGS tools, such as StreaMail, that provide real-time alerts. An ACF Stakeholders group enables constructive dialogue. Atlanta is promoting green infrastructure and adopting water conservation practices. The landscaping industry is re-organizing around water-efficient landscaping. The Lake Lanier Association is educating school children and the public about this threatened resource.

Intense dialogue is underway about ways (some controversial) to ensure adequate water supply against a backdrop of significant population growth and changing precipitation and watershed characteristics – debating ideas such as new or expanded reservoirs, inter-basin transfers, aquifer recharge systems, restoring natural hydrology, and expanding water conservation.

While the utilities themselves can only do what is under their control, they are working to leverage their approach toward integrated water resource management and adaptive preparedness to ensure reliable service.

To learn more about how the water sector is responding to extremes, visit:

<http://www.cpo.noaa.gov/ClimatePrograms/ClimateSocietalInteractionsCSI/SARPPProgram/ExtremeEventsCaseStudies.aspx>

Lessons Learned

- Collaborating with other organizations and governing bodies responsible for water management helps foster integrated solutions.
- Communicating and collaborating with stakeholders, including the media and elected officials, is critical for educating the public and creating long-term solutions.
- Engaging with existing regional planning structures, such as water planning councils and state initiatives, is challenging but could help promote long-term planning for multiple objectives.
- Planning must integrate science, conservation, infrastructure, and management.



Consecutive extreme events hit north Georgia hard. (Top) Normal water levels at Lake Lanier are 1.8M acre feet. (Middle) By late 2008, drought put the reservoir at 50% capacity; the area suffered \$326 million in recreational use and property value losses, plus tax and income losses. (Bottom) Flooding in 2009 at Gwinnett County's wastewater utility caused \$7.5 million in repair work.



- “What if” planning for worst-case scenarios can help identify vulnerabilities for advance preparedness.
- Familiarity with how the Federal Emergency Management Agency (FEMA) operates helps with restoration efforts.

Useful Tools and Resources

- Georgia Water/Wastewater Agencies Response Network (GA WARN)
- NOAA National Integrated Drought Information System (NIDIS)
- US Geological Survey (USGS) WaterAlert and StreaMail

Information Needs

- Forecasts for short-term intense storms and longer-term droughts, especially at a local level
- Targeted vulnerability assessments
- Modeling for south Georgia that includes Florida
- Water demand and use estimates
- Updated floodplain maps
- Updated engineering design manuals

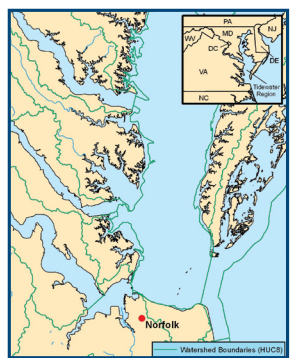
Case Study

Virginia: Tidewater Area



Water Resource Strategies and Information Needs in Response to Extreme Weather/Climate Events

Tidewater Area



Water Trends

Tidewater Virginia is subject to storm surges, tidal flooding, hurricanes, and nor'easters. Since 1970, there have been ten significant storms, the majority since 2003. Significant storms are predicted to become more frequent.

The lower Tidewater area is second in the continental US for risk of hurricanes, storms, and sea level rise (SLR). Risks are high because of area population growth and national security assets. Relative SLR is accelerated by land subsidence due to compaction of underlying soil formations, and groundwater withdrawal. The Sewell's Point gage at the Norfolk Naval Station has recorded a sea level rise of 14.5 inches since the late 1920s. Scientists predict a local relative SLR of 1.5-feet in the next 40 years and three feet by 2100.

The region is subject to saltwater intrusions into fresh water. SLR threatens the coastal ecosystem, with potential loss of 50% – 70% of wetlands. With 85% of Virginia's shoreline privately owned, this has economic implications for residents, commerce, military installations, and utility services.

Governing Structures

The Hampton Roads Sanitation District (HRSD) is the only sanitation district in Virginia. HRSD owns the treatment plants; the cities own the collection systems and are responsible for stormwater management. Virginia has 21 planning districts, but local governments make all land use decisions. While every locality has a comprehensive land management plan, some allow development in flood-prone areas.

Naval Facilities (NAVFAC) Engineering Command Mid-Atlantic is responsible for design, construction, and maintenance of Navy facilities but gets its water and wastewater services from the municipal systems, as do the other military installations in the Tidewater area.

The Story in Brief

"Tidewater" is the eastern Virginia coastal plain where the James, Rappahannock, and York Rivers join the Chesapeake Bay. Within the lower Tidewater there are four cities (Hampton, Newport News, Norfolk, and Virginia Beach), rural and small communities, military installations including the world's largest naval station (the Norfolk Naval Base), and a large state-owned cargo port. Three metropolitan drinking water utilities and one sanitation district serve 1.7 million people. The region has many wildlife refuges and recreational beaches, alongside areas of dense development. All of this sits at an average 33 feet above sea level, posing challenges to the area's water and wastewater utilities and to the delicate balance between fresh and salt water in the estuarine environment, especially in light of heightened storm threats.

Hurricanes, Nor'easters, and Sea Level Rise (SLR)

Impacts

In 2003, Hurricane Isabel, a slow-moving storm, stalled over the York River during high tide causing storm surges to reach record highs. Isabel killed 36 people in Virginia and caused more than \$1.8 billion in damage, cutting off electricity for 1.8 million customers. Again in 2009, Nor'easter Ida caused some of the worst damage ever experienced in the area. Ida lasted six tidal cycles with winds pushing water above the 4.5-foot flood stage and creating surges over 6.7 feet.

Given this history, in August 2011, before Hurricane Irene's predicted arrival at Hampton Roads, Virginia's governor declared a state of emergency. The US Navy sent dozens of ships to sea, universities closed, ferries were stopped, both mandatory and voluntary evacuations were ordered, and water/wastewater utilities activated their emergency response plans. The storm stalled over the area. By high tide, storm surges over 7.5 feet at Sewell's Point were recorded.

On August 25 and 28, 2012, two "short-fuse" nor'easters hit the same 30-square-mile area with high rainfall (2-3 inches/hour) over a short period (2-4 hours), each exceeding a "hundred-year" event.

The most widespread impacts from these events were flooding and power failures. Uprooted trees triggered water line breaks requiring expensive repairs. Isabel caused 250 of 400 small wastewater pump stations to lose power. Ida caused 60% of Virginia Beach's outfalls to fill with silt and caused a partial dam failure on the Chickahominy River. At the Norfolk Naval Base, the storms caused base and roadway flooding, over-topped piers, disrupted utilities, eroded the shore line, caused pier and bulkhead scour, destabilized the ground, and increased loads on structures.

Water and wastewater facilities built on shorelines are particularly vulnerable. Coastal erosion is affecting infrastructure. SLR is causing salinity of inland water sources, and utilities are recording salt water at their intakes. Newport News raised its reservoir water level one foot to keep freshwater upstream and brackish tidal water downstream. SLR inhibits drainage, raising risks from disease vectors like mosquitoes.

Water Utility and Community Response

The severity and frequency of recent storms have motivated localities to collaborate for both acute emergencies and long-term planning by conducting what-if and worst-case scenario analyses and tabletop exercises to consider asset and operational vulnerability. Utility managers share information and seek common funding sources and methods.

To prepare for acute events, local utilities have adopted "action tables" for each wastewater facility on how to respond based on various storm tide levels. After-action reports help managers refine emergency operations, review water levels and flows, and evaluate operational performance. Utilities and other agencies identify critical redundancy needs, such as deploying portable backup pumps and generators prior to events. Widespread dependence on cell phones, which themselves are dependent on electricity, has prompted use of system backups for operations, and utilities are working to align plans with private-sector telecom providers to ensure reliability. Innovative mechanisms have

"Local governments are faced with the realities of sea level rise and coastal storm impacts and they are in need of solutions and assistance to deal with these challenges."

Dr. Carl Hershner, Director of the Center for Coastal Resources Management, VIMS

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been adopted to disseminate information to the public, including the Norfolk Flooding Website (an emergency alert system), Facebook, and Twitter.

To increase long-term resilience, Norfolk is redesigning its 60-year-old drainage system. Inserts in manhole covers help reduce infiltration into sewer lines. Water systems are monitored for saltwater intrusion, and an aggressive effort is underway to identify and remove trees that can take down power lines or pull up and damage water lines. To prevent damage from repetitive flooding, managers are raising control panels, installing watertight doors and hatches, and moving portable equipment to higher ground during storms. Dam managers are improving overflow structures to relieve pressure, and they have an active inspection program to prevent damage from trees and rodents.

The Naval base's strategic importance and position, sixteen feet above sea level, has prompted it to incorporate SLR into its Master Plan, Region Shore Infrastructure Plans (RSIP), and Global Shore Infrastructure Plan (GSIP). Measures being evaluated include building new unloading decks with utility lines and shutoff valves safely above potential water levels, adapting existing infrastructure with flood walls around dry docks and installing tide gates, raising pier elevations, and siting facilities out of impacted areas. The Navy is engaging in shoreline protection projects, including adopting low impact development to reduce runoff. It has expanded its damage assessment teams and emergency operations center and is working with the local community on areas of mutual concern. However, challenges abound. For example, the Navy can elevate buildings and land, but must consider load-bearing capacity of underlying infrastructure, base access, and utilities on and off base.

Looking Forward

Utilities are grappling with environmental challenges, aging infrastructure, and a struggling economy along with a changing climate. Critical high-cost investment priorities are causing utilities to reach limits set by US EPA's Affordability Guidelines and are stretching communities' ability to pay.

Nonetheless, there is a growing awareness of the need to manage risk and to take a proactive approach to protecting current assets and preserving ecosystem functions. The Tidewater region is deploying new and more sophisticated technologies. For example, they are undertaking comprehensive LIDAR (light detection and ranging) airborne laser mapping that they will combine with ground topography and elevation mapping to help citizens identify their risks and to improve floodplain management.

Water managers expressed a need to raise the public's understanding of the difference between impacts and responses to tropical storms vs. nor'easters so that public and private solutions are effective in both cases. The public also needs access to accurate and timely information for decision making.

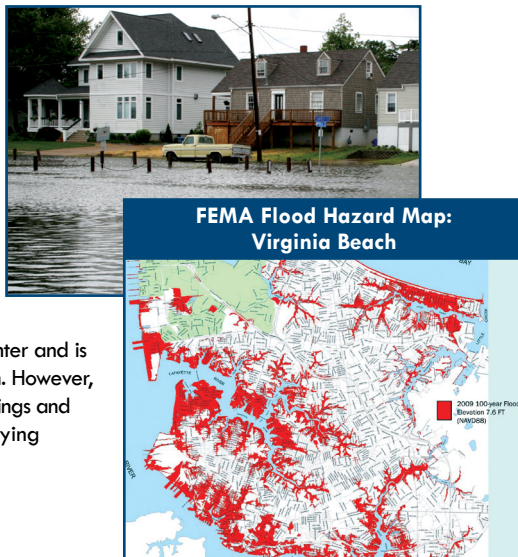
Virginia promotes regional collaboration and intergovernmental relationships through active regional planning commissions and citizen boards, such as HRSD and Hampton Roads Planning District Commission. Engaging area utilities, including those in rural areas, has the potential to increase the effectiveness of a coordinated regional approach to building resilience.

The Navy is an important actor and its installations are an integral part of the regional planning process. The Virginia Institute of Marine Science (VIMS) and Virginia Emergency Management Association (VEMA) are important partners in understanding and responding to risk from extreme events. The work of VIMS and the Virginia Department of Environmental Quality in promoting living shorelines to control ecosystem erosion is a vital aspect of adaptive planning.

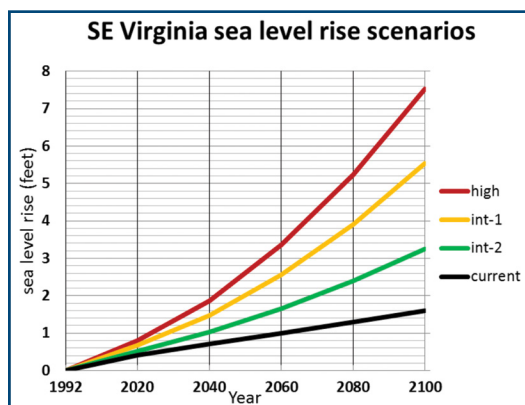
Although limits exist on what individual water utilities can do given their resources, understanding, and authority, they are increasingly integrating their resources and strengthening their relationships with other water managers, private service providers, and federal and other agencies, thus increasing their resilience and further minimizing risks.

To learn more about how the water sector is responding to extremes, visit:

<http://www.cpo.noaa.gov/ClimatePrograms/ClimateSocietalInteractionsCSI/SARPPProgram/ExtremeEventsCaseStudies.aspx>



(Top) The cost of raising one block of housing above flood level is about \$1.2 million in Norfolk, VA. (Middle) FEMA's flood hazard map of Virginia Beach shows how floods threaten areas. (Bottom) Sea level rise scenarios show four estimates based on 2012 National Climate Assessment global scenarios. Even a conservative estimate (green) predicts a 1.5-foot (0.5 m) SLR by 2052.



Lessons Learned

- What-if and worst-case scenario planning can help prioritize budgets and future response actions.
- Solutions require sensitivity to people's values and concerns.
- Hard asset locations should be assessed and operational "brain centers" moved from at-risk areas.
- Tools for rapid communication are essential for controlling messages and ensuring quick and appropriate emergency responses.
- Local communities need flexibility to implement local solutions.
- Engineering design standards must be based on the reasonableness of expected levels of service, sensitivity of facilities, criticality of assets, and budgets.
- Backup power must be provided for critical systems and communications.
- Real-time data and alerts, which can be shared among fusion centers, and emergency operations centers, must be accessible.

Useful Tools and Resources

- Virginia Interoperability Picture for Emergency Response (VIPER) – a GIS-based platform that links data
- WebEOC – a web-based emergency operations center, run by the Virginia Department of Emergency Management
- Water Agency Response Network (WARN)

Information Needs

- Improved forecasts for short-term and less-intense storms, especially at a local level
- Socioeconomic impact studies
- More sophisticated models that include different elevations and levels of inundation and that incorporate SLR, precipitation, bathymetry, storm surges, high tides, hurricanes, and nor'easters
- Public education on risks and differences between flooding and storm surges
- Information and incentives to help land- and home-buyers make educated decisions about their investments
- Guidance to water and wastewater facilities on how to incorporate new information on SLR estimates in their planning approaches and on understanding what HAS happened versus what COULD happen
- Grants to help smaller communities plan

Case Study

Washington DC: National Capital Area



Water Resource Strategies and Information Needs in Response to Extreme Weather/Climate Events

National Capital Area



Water Trends

The Washington metropolitan region sits along the Potomac River, which provides about 90% of the region's drinking water. The topography ranges from near sea level along the Anacostia and Potomac to about 400 feet above sea level.

MWCOG reports that the region is experiencing the effects of climate change with rising sea levels and a warmer Chesapeake Bay – more than 2°C (3.6°F) in the past 70 years. NOAA climate models show that sea level rise will impact Washington, DC, and the frequency and severity of extreme events likely will increase. The region is increasingly vulnerable to tropical storms and nor'easters, heat waves, and heavy rains that cause flooding.

Drought that impacts potable water systems is far less severe here than elsewhere in the US. However, the forecasted increase in population will put additional stress on infrastructure and water resources. A recent ICPRB study estimates regional water shortages by 2040.

Governing Structures

The Washington metropolitan region has a history of well-organized regional coordination. MWCOG coordinates among local governments and utilities on a broad range of issues. The ICPRB coordinates the region's water supply. Three major water supply agencies treat about 95% of the region's drinking water: the Washington Aqueduct Division of the US Army Corps of Engineers, the Fairfax County Water Authority, and WSSC. Water is distributed by numerous utilities and local governments. The area has 19 major wastewater plants managed by 7 local governments or authorities. DC Water runs the Blue Plains Advanced Wastewater Treatment Plant, one of the largest in the country, and collects and manages wastewater from parts of Maryland and Virginia suburbs. More than 20 county and city governments manage stormwater.

The Story in Brief

Two exceptional extreme events struck the Washington metropolitan area in 2012 that provide insight into the value and cost of utility and community preparedness. With little warning, a rare derecho windstorm left a swath of wind damage in its path. Four months later and after a week of tracking and preparation, "Superstorm" Sandy devastated much of the East Coast. The Washington region was largely spared, but many lessons were learned from full-scale emergency preparation. These two events highlighted critical interdependencies between power, transportation, and water infrastructures and the need for more coordinated planning for resiliency.

The Derecho, 2012

Impacts

On June 29, 2012, a fast-moving, large, and violent thunderstorm called a derecho slammed the region with less than a day's notice, bringing with it winds upwards of 85 mph. It hit during record-high temperatures when residents used peak levels of water and power.

Phone systems went down or were overloaded from a combination of power outages and surges. The Washington Suburban Sanitary Commission (WSSC), seriously affected by downed power lines in its heavily treed service area, lost power at both the Potomac and Patuxent filtration plants and at more than 50 of its facilities. Water storage tanks were only at 65% capacity, since the derecho arrived before nightly recharge. Also, a large water main was out of service for repair. Together, these required water restrictions, although water service continued. Closed streets from downed trees hampered efforts to move and fuel mobile generators. On the plus side, subsequent tree trimming may have helped reduce problems when Superstorm Sandy arrived.



The June 2012 Derecho caused extensive tree damage contributing to power outages in some areas that impacted water service.

Emergency managers faced challenges because the derecho hit at the start of the Fourth of July holiday. While area governments were closed, relieving traffic, many responders could not commute to work as the Metro bus and rail system was disrupted by downed trees and power lines. The electric utility found that restoring power to the treatment and distribution facilities was time consuming because of extensive damage; however, the total costs of the derecho for WSSC were minor compared with the considerable cost of debris removal.

Local Government, Utility, and Community Response

Response to the derecho was mainly reactive, and utilities addressed issues as they arose. After the derecho, the DC Department of Homeland Security implemented an improved planning process with clearly defined roles and responsibilities, improved training, and began using FEMA's WebEOC to track resources and manage logistics.

WSSC benefited from facility prioritization work it had done with local power companies Pepco and BGE following a 2010 storm. Had that prior work not been done, recovery from derecho outages would have taken even longer. Following the derecho outages, Pepco and BGE agreed to further update the list of water facility priority restorations. The extensive power outages following the derecho also resurrected discussions between WSSC and surrounding counties regarding whether an onsite 10 MW generator should be built at the Potomac Water Filtration Plant. DC Water had already begun a biosolids digester project that would use onsite combined heat and power to reduce their reliance on the electrical grid.

Superstorm Sandy, 2012

Impacts

On October 22, 2012, NOAA's National Hurricane Center issued an advisory for the 18th named tropical depression of the season. This would become the largest and second-costliest Atlantic hurricane in history. By October 24, the

A series of workshops focusing on extreme events and water resources, co-sponsored by the National Oceanic and Atmospheric Administration (NOAA), US Environmental Protection Agency (US EPA), Water Environment Research Foundation (WERF), Water Research Foundation (WaterRF), Concurrent Technologies Corporation (CTC), and NOBLIS.

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advisories turned into warnings for “Hurricane Sandy.” Mid-Atlantic communities were on high alert, when, at 8:00 pm on October 29, Sandy made landfall as a post-tropical cyclone along the coast of southern New Jersey and her destruction began.

All this time, communities including water utilities in the Washington metropolitan area had been making full-scale preparations for hurricane-force winds, coastal and inland flooding, and blizzards. Fortunately, it skirted the service area, so Sandy had minimal effects on area water utilities, and most provided uninterrupted service through the event.

Several utilities experienced short power outages and a few sewer overflows. Fairfax County suffered flooding in low-lying communities along the Occoquan River. Costs were related mostly to overtime pay for planning and maintaining “alert” status (about \$500,000 at WSSC), plus the not insignificant cost of deploying backup generators. Otherwise, Sandy mostly acted as a valuable “drill” event and revealed several areas for improvement.

At the Smithsonian Institution, a direct hit would have caused some \$500M in damage. Most of its buildings are on the National Mall (within a foot or so of sea level) where billions in assets are stored in basements. Since a June 2006 flood it had been working to waterproof underground spaces. During Sandy, the National Gallery of Art and American History Museum were threatened by flooding from backed-up storm drains.

Local Government, Utility, and Community Response

The Metropolitan Washington Council of Governments (MWCOG) regularly coordinates emergency preparedness calls. About 10 days before Sandy was predicted to hit, DC Water activated its own emergency management plan, which included daily calls with its trained response teams. The public information website was updated. The utility flood-proofed perimeters that were not already hardscaped and moved equipment that could be most affected. Logistics related to chemical inventory and biosolids hauling were put in place. Fairfax County, with one of the most sophisticated emergency management programs in the country, began using its multi-media citizen alert network well in advance and opened shelters. As with other jurisdictions, its flood maps are automated, but flood data were not localized enough for targeted block-by-block response (evacuating communities too frequently causes citizens to ignore warnings).

The long lead-time that kept the response community on alert for days proved exhausting. It revealed a weakness in water utility plans for staffing, including housing, provisions, and transportation; deployment, relief and stand-down schedules; and unscheduled pay. Conveying central planning decisions to field staff was challenging. Further, utilities reported that no amount of planning could stop power outages and flooding, making it critical that they manage customer expectations – and their own.

Most area water utilities conducted post-Sandy debriefs to improve emergency operations and instituted improved plans and mechanisms. However, questions remain about how to reduce the region’s vulnerability to flood-inducing storms and power outages. Area planners, including the National Capital Planning Commission (NCPC), MWCOG, the Interstate Commission on the Potomac River Basin (ICPRB), and a consortium of federal facilities managers, became engaged in ongoing dialogue.

Looking Forward

Water utilities found that the pressure of short-term budget realities can conflict with the need to understand and address long-term risks. Many are investing in strategies that increase resilience. While improvements are evident in the way local jurisdictions and utilities communicate, plan, and train for emergency response, water professionals throughout the Washington metropolitan region are recognizing the need for more integrated planning among the various jurisdictions and service entities to build resilience to extreme and costly weather events. Planning and implementing this kind of approach would benefit from a public conversation to expand understanding of the various causes of flooding and service disruptions to enable them to make choices that meet near-term needs while building long-term adaptive preparedness.

To learn more about how the water sector is responding to extremes, visit:

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(Top) NOAA's satellite image of Superstorm Sandy.
(Bottom) Workers place sandbags in advance of Superstorm Sandy to protect buildings from flooding.



Lessons Learned

Emergency Response:

- Dependence on power is a major vulnerability (electricity and fuel).
- Supply chain plans are necessary for the number of days it takes to reach criticality, e.g., chemicals, fuel.
- No amount of after-action reporting will make up for direct experience.
- Planning for personnel provisions, communication, and transportation is critical for events with long durations.
- Public expectations must be managed and individual preparedness encouraged.

Long-Term Planning:

- Integration at a regional scale is needed given the multi-state and federal presence in the region. Multi-jurisdictional organizations are well-suited to facilitate regional planning.
- Individual leaders drive the process.
- Planners now need to consider the changing hydrology as a factor in land-use planning.
- Stormwater managers need to expand understanding and integrate effective long-term investments to achieve both water quality goals and to manage flood water.
- Limited budgets are forcing trade-offs between short- and long-term actions.

Useful Tools and Resources

- MWCOG climate change activities
- ICPRB – water supply and reliability analysis under future climate scenarios
- Georgetown University Climate Center – model language for a sea level rise overlay district for zoning
- WaterRF Climate Change Clearinghouse
- US EPA CREAT tool
- NCR WARN and the Emergency Management Systems Compact (EMAC)
- FEMA Emergency Operations Center
 - ICS training programs and drills
 - Full Spectrum Risk Knowledge Base
 - All Hazards Consortium – planning for power outage of all of NE
 - Personal preparedness iPhone app
- US EPA Emergency Training
- NOAA NWS Advanced Hydrologic Prediction Service
- FloodSmart.gov – insurance and funding information

Information Needs

- More accurate and localized flood data
- Improved projections for frequency and intensity of extreme events
- Real-time data and monitoring
- Translated river elevation data to show what river stage means
- Methods for determining long-term costs and benefits of climate-adaptation investments

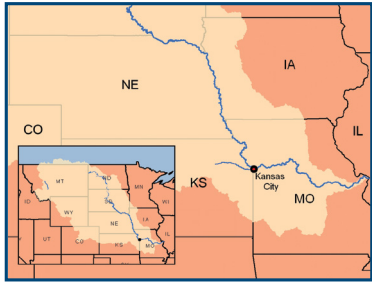
Case Study

Kansas/Missouri: Lower Missouri River Basin



Water Resource Strategies and Information Needs in Response to Extreme Weather/Climate Events

Lower Missouri River Basin



Water Trends

The LMR stretches from Gavin's Point Dam to its confluence with the Mississippi River. Snowmelt originating in the Rocky Mountains makes up 75% of its water from March-July. The Kansas River, a major tributary joining the LMR at Kansas City, is fed by four reservoirs for water supply, flood control, and endangered species habitat.

The region is known for extreme weather variability. The northern areas of the Great Plains are likely to get wetter while the south and west are likely to get drier due to reduced rainfall and higher temperatures. The LMR lies at the intersection of climate regions, making local water projections difficult. The Rockies are likely to experience earlier spring snowmelt.

Governing Structures

On the Missouri River, USACE operates six major dams for flood control, navigation and bank stabilization, irrigation, hydropower, water supply, water quality, recreation, and fish and wildlife. The Missouri Water Resources Center manages quantity and quality of the state's water resources, advised by the State Water Plan Inter-Agency Task Force. The Kansas Department of Agriculture's Division of Water Resources regulates water through the Water Appropriation Act, and the Kansas Water Office oversees reservoir storage contracts.

Drinking water service in Kansas City, MO, is provided by the city's Water Services Department, operating water, stormwater, and wastewater utilities. Johnson County, a Kansas City suburb, operates its own stormwater and wastewater departments. Drinking water is supplied by WaterOne, a quasi-municipal government. Smaller cities and communities in the metro Kansas City area provide their own water services, including stormwater management.

Twenty-eight Indian tribes live in the Missouri River basin. The tribes have not fully exercised their water rights to date.

The Story in Brief

The Lower Missouri River (LMR) basin has long experienced extreme weather and climate events. Over the last 20 years, the basin has faced increasing frequency and severity of flood and drought. Communities endured record floods in 1993 and again in 2011. Recent droughts, including the ongoing drought of 2012/13, have ignited tension over water supplies and river flows in a region that perceives itself as having plenty of water. For utilities on the Missouri River, the issue is low water levels due to riverbed degradation, not availability of water itself. Water utilities also are struggling with the lack of sufficient water storage in the Kansas River tributary. Managing the LMR to control flash flooding, protect water quality and habitat for endangered species, as well as support the agriculture and barge-based economy, provides a challenging context.

Great Floods of 1993 and 2011

Impacts

During the flood of 1993 the LMR combined with the Mississippi River to become the largest recorded flood in the United States, with water levels topping the previous flood of record by 20%, affecting 150 major rivers and tributaries. It caused 50 deaths, hundreds of failed levees, and thousands of evacuations that lasted months. Damages totaled \$85 million for water and wastewater utilities. Some 200 municipal water and 388 wastewater systems were damaged, many in the Lower Missouri River Basin. Repeated flooding along with dredging and other activities has contributed to riverbed erosion.

In 2011, a new record flood hit the Lower Missouri. In the upper basin, melting snowpack combined with record rainfall from May to July (102 inches vs. a normal 25 inches) resulted in runoff that exceeded the 1993 flood by another 20%, flooding the lower basin. The US Army Corps of Engineers (USACE) opened two spillways on the dam system that had never before been operated under wet conditions, reducing water levels by seven feet to accommodate the deluge.

In Missouri, Kansas City's only water plant experienced high flows, creating turbidity and debris that settled in primary tanks. In Kansas, Johnson County Wastewater's seven treatment plants experienced power failures, and communities endured sanitary sewer overflows and basement backups.

Utility and Community Response

Localities collaborated to find regional solutions to flooding and river issues. The Mid-America Regional Council (MARC), the planning organization for the bi-state Kansas City region, began working on solutions to prevent riverbed degradation, improve bank stabilization, and accelerate sustainable ecosystem restoration projects. The USACE protected the metro area with a system of seven levees. In 2011, flood levees largely performed as designed.

WaterOne, which supplies drinking water to most of Johnson County, KS, reported that impacts from the 2011 flood were minimal because it planned for 500-year floods. However, floodwater isolated its Missouri River intake collector, which continued to operate during the event.

More than 25 years ago, Johnson County Wastewater accelerated its program to prevent rainwater infiltration and inflow into sewer lines by implementing a program to remove or upgrade private sources and to improve prevention and maintenance. After the 2011 flood, Johnson County's disaster recovery plan added data backups, real-time monitoring at standby locations, and redundant communication systems. The utility installed electrical power from a second, independent feed, and it put in both mobile and onsite generators. Its combined heat and power capability could run one plant independently in "island" mode.



The Kansas City, Missouri, Water Treatment Plant during the flood of 1993.

A series of workshops focusing on extreme events and water resources, co-sponsored by the National Oceanic and Atmospheric Administration (NOAA), US Environmental Protection Agency (US EPA), Water Environment Research Foundation (WERF), Water Research Foundation (WaterRF), Concurrent Technologies Corporation (CTC), and NOBLIS.

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Local entities coordinated throughout the 2011 flood with the Kansas State Department of Emergency Management, the Kansas City Emergency Operations Center, and the Missouri River Joint Operations Center. After the flood, utilities recognized the valuable role for Missouri and Kansas Water and Wastewater Agency Response Network (WARN).

Drought of 2012/13

Impacts

Drought conditions began in 2012 and were expected to persist through 2013. The water levels in the Missouri River fell six to ten feet in some stretches by Kansas City. As of April 2013, more than three to nine inches of rain were needed to bring soil moisture back to normal. The region was expecting temperature increases and greater evaporation. Low river levels had already resulted in \$500 million in economic losses since 2012.

Low reservoir releases in the winter created problems for municipal and industrial water intakes along the Lower Missouri River. Because of past floods and man-made activities, the river bottom degraded, lowering the river elevation over the last 30 years at Kansas City by ten feet. This degradation exacerbated the impact of low flows during drought. As a result, Kansas City, MO, Water Service Department installed structural solutions at the intakes in the 1980s and 2009 to address declining water levels. Expensive new retrofits were on the horizon unless USACE's operating rules change to allow greater dam releases. At the WaterOne intake, the low Missouri water levels required more energy for the low water pumps, costing \$20,000 additional per year.

In 2012, questions arose about the need to release water from reservoirs on the smaller Kansas River tributary to protect navigation and habitat on the much larger Missouri when future drinking water supply was at stake. Soaring temperatures fostered toxic algal blooms in reservoirs, raising health concerns and causing severe taste and odor problems for drinking water, requiring treatment at \$750,000 per year.

Several water utilities with shallow or older pipes had expensive breaks as lines shifted in extremely dry soil. Kansas City was considering burying small mains deeper, a costly endeavor.

Utility and Community Response

Potable water service was not interrupted in the basin, but the drought seriously threatened the economy, water utility infrastructure, and water access. It worsened tensions between USACE and water users in Kansas, a western water rights state. Competition for water throughout the basin has stimulated debate about asking Congress to prioritize power and water supply among USACE's authorized purposes for the Missouri River. It remains to be seen how the communities will balance competing needs as the current drought persists.

Over the years, WaterOne had responded to river level decline by installing low water pumping equipment on the LMR intake and a permanent weir on the Kansas River intake to sustain channel flows. Estimated capital costs for fixing existing intakes would top \$128 million, with new intakes costing \$286 million across water service providers throughout the LMR basin. During this drought, the Kansas Water Office encouraged conservation measures.

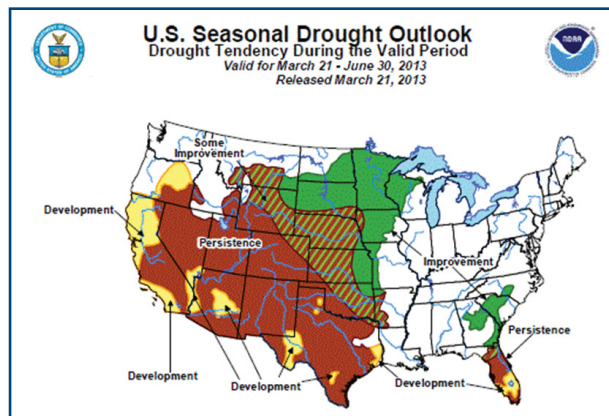
To encourage regional planning and sustainable watershed management, MARC began promoting water quality conservation, green infrastructure, and additional efforts in watershed planning. To date, projects involved multiple local sponsors, including WaterOne, Kansas City, KS, and USACE. For water utilities that depend on fees for revenue, water demand reduction measures were seen as revenue reducers. Further, public perception that there is plenty of water in the Missouri River caused resistance to conservation measures.

Looking Forward

The long history of efforts to control the Missouri River has yielded disparate authorities, different legal frameworks, and water rights that confound a ready resolution to these complex issues. Utilities are improving planning and infrastructure, as well as building on collaborations and seeking innovative solutions. They are expecting that federal agencies will provide better access to useful forecasting and data. However, water utilities worry that a proposed Missouri River Compact could create multiple lawsuits, which delay solutions. Many believe that USACE, emerging stakeholder alliances, and top-rate data sets remain the most likely mechanisms for balancing intertwined and entrenched water management needs.

To learn more about how the water sector is responding to extremes, visit:

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NOAA forecasts reduced rainfall and higher temperatures, increasing the risk of drought in much of the basin.

Lessons Learned and Challenges

- People do not understand residual flood risk and relationship-to-return (e.g., 100 year) floods.
- Floods are inevitable; better pre-planning for logistics is required.
- State water laws differ between Missouri and Kansas, impacting the opinions and perceptions of water users in each state.
- Trusted information sources are critical. Informal communication prevails.
- Access to and interpretation of data is an issue for operations and emergency response. Users need to identify what is most useful for their stakeholders.
- Mutual aid agreements are important to collaborative regional networks.
- Insurance policies need to discourage building in flood plains.
- Aging infrastructure, payment for true cost of water, and inefficient water use must be addressed.
- Asset management is key to being prepared for extreme events.

Useful Tools and Resources

- FEMA floodplain maps – msc.fema.gov
- US EPA WaterSense program – www.epa.gov/watersense/
- USGS Water ALERT rain gauges, gauge-adjusted radar system
- USACE interactive monitoring website – <http://www.nwcd-mr.usace.army.mil/rcc/>
- Stormwatch.com (24-hour real-time monitoring system) – www.stormwatch.com
- Kansas Water Assurance District Display – www.ksda.gov/water_management_services/about/
- Sediment transport model built by USACE
- NOAA Missouri Basin Experimental Monitoring and Forecasting Portal – www.esrl.noaa.gov/psd/csi/monitor/mobasin/index.html

Information Needs

- Information at decadal time scales.
- Level-of-service design standards for community infrastructure by location.
- Relevant, practical science and technology translated into useful tools.
- A dashboard to navigate among many federal data websites and to customize needed data that can be manipulated for daily, weekly, and monthly views.
- Large spatial and temporal-scale determinations converted for support of shorter-scale decision making.
- Real-time data and monitoring in key locations for soil moisture, precipitation, snow pack, and water level.
- Accurate and localized flood data.
- Regional information exchanges.

Case Study

Texas: Central Region



Water Resource Strategies and Information Needs in Response to Extreme Weather/Climate Events

Central Texas Region



Water Trends

The influence of El Niño Southern Oscillation (ENSO), specifically the La Niña phase, subjects Central Texas to frequent droughts. La Niña causes lower than normal precipitation for the southwest United States, reducing soil moisture and stream flow. The area is dependent on winter rain from the Atlantic for reservoir and aquifer recharge. Observed and projected trends of increased temperature make this region even more susceptible to drought.

Central Texas depends heavily on the Highland Lakes on the Lower Colorado River for the region's water supply, especially water stored in the Lake Travis and Buchanan reservoirs. In 2011, inflow into these lakes was only 10% of the yearly average. Inflows over the past five years were the lowest of any five-year period in recorded history.

Communities south of Austin, including the city of San Antonio, rely on small karst aquifers that are prone to multi-year drought cycles. The lack of winter precipitation for recharge from the Mid-Atlantic Oscillation (MAO) combined with burgeoning population growth threaten the sustainability of area aquifers.

Governing Structures

Established by the Texas Legislature in 1934, the Lower Colorado River Authority (LCRA) is a conservation and reclamation district that relies solely on revenues generated from supplying energy, water, and community services. Six dams and reservoirs comprise the LCRA system and form the Highland Lakes. LCRA operates the reservoirs for water supply, flood control, and power generation.

Groundwater is managed by conservation districts authorized by the State of Texas. Cities manage their own water, wastewater, and stormwater services.

The Story in Brief

Central Texas entered its third consecutive year of drought in 2013, which began in 2011 when the state endured its worst single-year drought and hottest summer in recorded history. That year, communities in Central Texas faced 90 days of triple-digit heat, during which extensive wildfires burned hundreds of homes. Heading into the 2013 summer season the reservoir system on the Lower Colorado River was at even lower levels than at that same time in 2011. For the second year in a row the Lower Colorado River Authority (LCRA) had not released water for downstream agricultural uses that had an 'interruptible' standing under water rights provisions, which meant they could be curtailed. Urban users had purchased 'firm' water, available in a drought, resulting in the perception that there was plenty of water and creating tension with downstream agricultural users. Challenges persisted both in instituting an ethic of water conservation and in funding utility operations when selling less water.

Drought of 2011 to 2013

Impacts

Low winter rain and high summer temperatures caused an extreme drought in Central Texas in 2011. Lakes Travis and Buchanan, the area's main water supply reservoirs, and area aquifers were severely depleted. Water use restrictions caused an estimated \$35 million in revenue loss in Austin from 2011 through March 2013. The Barton Springs/Edwards Aquifer Conservation District (BS/EACD) also imposed pumping restrictions.

One of the most severe consequences of the 2011 drought was the extremely destructive wildfires in Bastrop County. The drought left the county vulnerable to wildfires, due to severely low field moisture. The resulting wildfire on Labor Day weekend 2011 destroyed more than 1700 homes, and two lives were lost. Property damage totaled \$360 million, marking the Bastrop County wildfire as the most expensive and extensive property loss due to wildfire in Texas history. The wildfire ravaged ecosystems: more than 1.5 million trees were damaged and plans were made to plant 1 million seedlings over the next four years in order to quickly restore the forests to previous conditions.

As of March 2013, the region was on track for not only a third consecutive year of drought, but a summer season that was worse than the 2011 drought or one that matched the 1950s record drought. Water supply reservoirs in Central Texas were a mere 44% full compared to 75% at the same time prior to onset of the 2011 drought. South of Austin, the highly prized portion of the Edwards Aquifer, whose flows support the endangered salamander in Barton Creek, reached critically low levels. The drought was once again hitting economic sectors throughout Central Texas, including agriculture, microchip manufacturing, and energy production. Rice farmers were suffering their second consecutive year with reduced water release from LCRA; low reservoir levels were concentrating ions and metals in water, which could lead to defects and lost revenue for microchip manufacturing.

Water and Utility Community Response

The State of Texas requires communities to adopt water conservation plans and drought management plans. However, drought plans are typically only implemented once communities are in the midst of drought. In Austin, a community

"It does appear that drought is the new normal."

Ken Kramer, Water Resources Chair
Sierra Club, Lone Star Chapter



Extreme low water levels due to the drought are evident at Lake Travis in Austin, Texas.

A series of workshops focusing on extreme events and water resources, co-sponsored by the National Oceanic and Atmospheric Administration (NOAA), US Environmental Protection Agency (US EPA), Water Environment Research Foundation (WERF), Water Research Foundation (WaterRF), Concurrent Technologies Corporation (CTC), and NOBLIS.

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known for its innovation and conservation ethic, the severity of the drought required water conservation that affected the City's revenue. In 2011, a revenue-stability fee was added to customers' bills to fund fixed costs. This fee was subsequently eliminated in 2012 with the adoption of a residential-tiered minimum charge based on monthly water usage, resulting in a lower charge for low water users and a higher charge for high water users. The City of San Antonio uses a rate structure that incentivizes conservation while maintaining adequate revenues.

During the 2011 Bastrop County wildfire, a well-prepared emergency response team evacuated 5,000 people in 2.5 hours. Firefighters assisted water utility personnel and vice versa – firefighters reported melted meters and pipes spewing water; utility personnel protected by firefighters restored water pressure. This event demonstrated the importance of established relationships and shared knowledge between emergency responders and water managers.

The private sector realized the need to protect itself from the rising cost of scarce water supplies. One microchip company, Spansion, evaluated its water use and adopted a cutting-edge suite of practices – FAB25. The FAB25 system increased energy and water efficiency, recovered contaminants from process wastewater for resale, and enabled reuse of reclaimed water. Spansion reuses 1.3 million gallons of water per day. Since 2008, this project has decreased its city water purchase by 22%. The agriculture community also worked to reduce water losses by updating irrigation equipment and adopting practices such as laser leveling fields.

As of early March 2013, BS/EACD, serving communities south and east of Austin was at Drought Alarm Stage II, which required permittees to curtail monthly pumpage by 20%. It is forecasted that both parts of the Edwards Aquifer will enter the Critical Stage III. The drought stages have associated requirements for residential water use (e.g., number of outdoor watering days allowed per week).

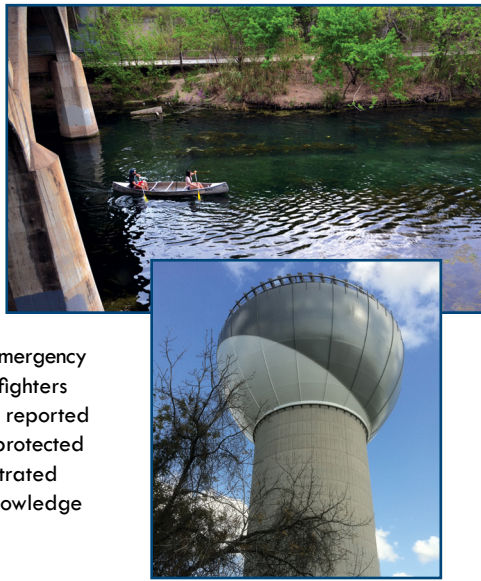
The city of San Antonio is the largest city in the nation that relies solely on groundwater for its municipal supply. Forced to adopt aggressive conservation measures in 1993 when it lost a lawsuit over the drawdown of the aquifer, the City implemented both demand management and supply management strategies. Its innovative measures include a rate structure that incentivizes conservation while adequately funding the utility. Despite doubling in population, San Antonio's water use remained the same due to their aquifer storage and recovery program, which supplies 15%–20% of its water demand. Its Drought Management Team convenes a weekly meeting to share information and develop strategies to ensure a rapid response in changing conditions.

Looking Forward

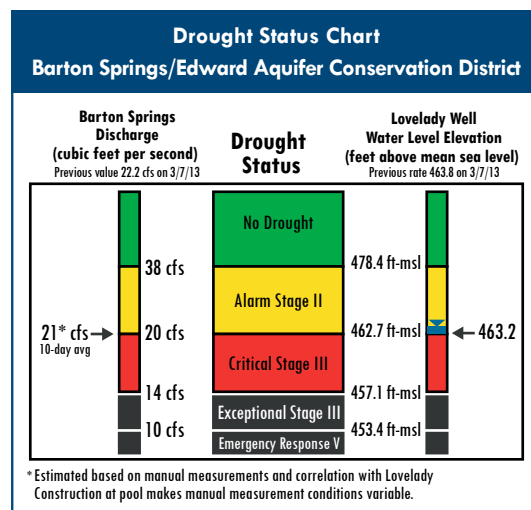
During the 1952 drought, fewer than 10 million people lived in Texas. The 2011 drought occurred with a population of 25 million that is projected to grow to 46 million by 2060. Increasing drought coupled with a growing urban population necessitates a strategy in which water conservation is standard operating procedure. Conservation would be viewed not as a drought management strategy, but as a way of life to support a vibrant economy and the beautiful natural resources that sustain it. Area water managers recognize this – building public acceptance is the challenge that lies ahead.

To learn more about how the water sector is responding to extremes, visit:

<http://www.cpo.noaa.gov/ClimatePrograms/ClimateSocietalInteractionsCSI/SARPPProgram/ExtremeEventsCaseStudies.aspx>



(Top) Lady Bird Lake in Austin has low water levels and algae blooms as a result of the drought, but boaters still enjoy an evening on the water. (Middle) The city of Austin uses reclaimed water from wastewater plants for watering landscapes and golf courses.



Lessons Learned

- Extreme weather can have secondary and tertiary impacts (e.g. droughts produce wildfires), requiring more coordination and collaboration.
- Integrated planning between water, agriculture, energy, health, and emergency services improves resiliency.
- Aquifer storage and recovery offers potential to bank water in times of plenty for use in drought.
- Water conservation is often confused with drought management.
- Drought Management Plans must be developed before drought strikes and implemented by drought stage triggers.
- The news media is an important partner in raising public awareness.
- Public reception can be improved by conveying information through trusted sources, which vary by community.
- It is vital to understand the roles of and build relationships among community service providers.
- Urban areas lack understanding of agriculture, exacerbating drought problems.
- Rate structure can incentivize conservation while maintaining adequate revenues for utility operations.

Useful Tools and Resources

- US EPA Climate Ready Water Utilities – water.epa.gov/infrastructure/watersecurity/climate/index.cfm
- TX WARN – www.txwarn.org
- LCRA – www.lcra.org
- USGS Water Resources Home Page – www.usgs.gov/water
- SAWS – www.saws.org

Information Needs

- Studies that evaluate the socio-economic impacts of drought.
- Formal analysis of reservoirs.
- Guidance for structuring water rates to provide adequate revenue while incentivizing conservation.
- Improved monitoring to support adaptive management.
- Local (vs. regional) monthly projections and seasonal and long-term forecasts of drought parameters.
- Translating data from models and gauges into useful reports to bridge the gap between researchers and stakeholders.
- Literature that promotes awareness, adaptation, and mitigation strategies.
- Increase the education of the American public on where their water comes from
- Federal government recognition of drought as an emergency situation. The emergency management community needs increased understanding of the water sector.
- Promote a more integrated dialogue across key energy and water providers.

Tools for Planning and Responding to Extreme Events

This list represents tools and information that workshop participants indicated were useful for local planning.

California: Russian River Specific Tools

NOAA National Weather Service California/Nevada River Forecast Center:

<http://cnrfc.noaa.gov>

California Water Science Center:

<http://www.scwa.ca.gov/srgw-studies>

Georgia: ACF Basin Specific Tools

GA Water/Wastewater Agency Response Network (GA WARN):

<http://www.gawarn.org/>

Georgia Environmental Protection Division River Basin Management Plans:

http://www.gaepd.org/documents/river_basin_management.html

US Army Corps of Engineers – Apalachicola-Chattahoochee-Flint Water Management:

<http://www.sam.usace.army.mil/pa/acf-wcm/bg3.htm>

Lower Missouri River Basin Specific Tools

US Army Corp Engineers – Missouri River Basin Water Management Division:

<http://www.nwd-mr.usace.army.mil/rcc/>

Overland Park Flood Warning System:

www.stormwatch.com

Kansas Water Assurance District:

http://www.ksda.gov/water_management_services/about/

Missouri Basin Experimental Monitoring and Forecasting Portal:

www.esrl.noaa.gov/psd/csi/monitor/mobasin/index.html

National Capital Area Specific Tools

National Capital Region Water/Wastewater Agency Response Network (NCR WARN):

<http://www.ncrwarn.org/>

Texas Specific Tools

Texas Water/Wastewater Agency Response Network (TX WARN):

<http://www.txwarn.org/>

Tidewater Area Specific Tools

Virginia Interoperability Picture for Emergency Response (VIPER):

<https://cop.vdem.virginia.gov/>

WebEOC:

<http://www.vaemergency.gov/search/node/WebEOC>

Virginia Water and Wastewater Agency Response Network (VA WARN):

<http://www.vawarn.org/>



National Level Tools

Collaborations:

Climate Change Adaptation Task Force:

<http://www.whitehouse.gov/administration/eop/ceq/initiatives/resilience>

Community Collaborative Rain, Hail, and Snow Network:

<http://www.cocorahs.org>

Emergency Management Assistance Compact:

<http://www.emacweb.org/>

National Integrated Drought Information System (NIDIS):

<http://www.drought.gov>

U.S. Drought Monitor:

<http://droughtmonitor.unl.edu/>

U.S. Global Change Research Program:

<http://globalchange.gov/>

Sea Level Rise Planning Tool for Hurricane Sandy Recovery:

<http://globalchange.gov/what-we-do/assessment/coastal-resilience-resources>

Water/Wastewater Agency Response Network:

<http://www.awwa.org/resources-tools/water-knowledge/emergency-preparedness/water-wastewater-agency-response-network.aspx>

EPA:

Climate Ready Estuaries:

<http://water.epa.gov/type/oceb/cre>

Climate Ready Water Utilities:

<http://water.epa.gov/infrastructure/watersecurity/climate/>

Climate Resilience Evaluation and Awareness Tool (CREAT):

<http://water.epa.gov/infrastructure/watersecurity/climate/creat.cfm>

Tools for Planning and Responding to Extreme Events

— Continued from Previous Page —

National Level Tools (Continued)

Emergency Response Training:

<http://water.epa.gov/infrastructure/watersecurity/emplan/index.cfm>

WaterSense:

<http://www.epa.gov/watersense/>

FEMA:

Map Service Center:

<https://msc.fema.gov>

<http://www.fema.gov/incident-command-system>

National Flood Insurance Program Floodsmart:

<http://www.floodsmart.gov>

National Incident Management System:

<http://www.fema.gov/national-incident-management-system>

NOAA:

Advanced Hydrologic Prediction Service:

<http://water.weather.gov/ahps2/>

Climate and Weather Forecasts and Outlooks:

<http://www.cpc.ncep.noaa.gov/>

Climate Program Office:

<http://www.cpo.noaa.gov>

Coastal Service Center Digital Coast:

<http://www.csc.noaa.gov/digitalcoast/>

Earth System Research Laboratory – Atmospheric River Information:

<http://www.esrl.noaa.gov/psd/atmrivers/>

Hydrometeorological Testbed:

<http://hmt.noaa.gov>

National Climatic Data Center (historical information):

<http://www.ncdc.noaa.gov/>

Sea Lake Overland Surge for Hurricanes (SLOSH) Model – National Weather Service:

http://www.nhc.noaa.gov/ssurge/ssurge_slosh.shtml

Sea Level Rise Data:

<http://tidesonline.nos.noaa.gov/geographic.html>

Sea Level Affecting Marshes Model (SLAMM):

<http://www.warrenpinnacle.com/prof/SLAMM>

US Army Corps of Engineers:

<http://www.corpsclimate.us/ccaceslcurves.cfm>

US Geological Survey:

<http://usgs.gov/water>

<http://water.usgs.gov/wateralert/>

<http://water.usgs.gov/hif/streamail>

<http://water.usgs.gov/nrp/gwsoftware/gflow/gflow.html>

National Weather Information Service (NWIS):

<http://waterdata.usgs.gov/nwis>

Data on Water Conditions:

<http://water.usgs.gov/watnow/>



To learn more about extreme weather and climate change, visit the sponsoring organizations' websites:

Water Research Foundation Climate Clearinghouse:

<http://www.theclimatechangeclearinghouse.org>

Water Environment Research Foundation Climate Website:

<http://www.werf.org/climatechange>

NOAA Sectoral Applications Research Program Website:

<http://cpo.noaa.gov/ClimatePrograms/ClimateandSocietalInteractions/SARPPProgram/ExtremeEventsCaseStudies.aspx>

US EPA Climate Change and Water Website:

<http://water.epa.gov/scitech/climatechange>